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Productivity of organic and conventional arable cropping systems in long-term experiments in Denmark

Ambreen Shah[a], Margrethe Askegaard[b], Ilse A. Rasmussen[c], Eva Maria Cordoba Jimenez[d], Jørgen E. Olesen[a,*]

[a] Department of Agroecology, Aarhus University, Blichers Allé 20, P.O. Box 50, 8830 Tjele, Denmark
[b] SEGES, Agro Food Park 15, 8200 Århus N, Denmark
[c] International Centre for Research in Organic Food Systems (ICROFS), P.O. Box 50, 8830 Tjele, Denmark
[d] Instituto de Investigación y Formación Agraria y Pesquera (IFAPA), Centro Alameda del Obispo, Córdoba, Spain

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A B S T R A C T

A field experiment comparing different arable crop rotations was conducted in Denmark during 1997–2008 on three sites varying in climatic conditions and soil types, i.e. coarse sand (Jyndevand), loamy sand (Foulum), and sandy loam (Flakkebjerg). The crop rotations followed organic farm management, and from 2005 also conventional management was included for comparison. Three experimental factors were included in the experiment in a factorial design: 1) crop rotation (organic crop rotations varying in use of whole-year green manure (O1 and O2 with a whole-year green manure, and O4 without), and a conventional system without green manure (C4)), 2) catch crop (with and without), and 3) manure (with and without). The experiment consisted of three consecutive cycles using four-course rotations with all crops present every year, i.e. 1997–2000 (1st cycle), 2001–2004 (2nd cycle), and 2005–2008 (3rd cycle). In the 3rd cycle at all locations C4 was compared with two organic rotations, i.e. O2 and O4. The O2 rotation in the third cycle included spring barley, grass-clover, potato, and winter wheat, whereas C4 and O4 included spring barley, faba bean, potato, and winter wheat. For the O2 rotation with green manure there was a tendency for increased DM yield over time at all sites, whereas little response was seen in N yield. In the O4 rotation DM and N yields tended to increase at Foulum over time, but there was little change at Flakkebjerg. The DM yield gap between organic and conventional systems in the 3rd cycle varied between sites with 34–66% at Jyndevad, 21–44% at Foulum, and 32–52% at Flakkebjerg. The inclusion of grass-clover resulted in lower cumulated yield over the rotation than the treatment without grass-clover. The use of manure reduced the DM yield gap between conventional and organic systems on an average by 15 and 21%-points in systems with and without grass-clover, respectively, and the use of catch crops reduced the yield gap by 3 and 5%-points in the respective systems. Across all crops the agronomic efficiency of N in manure (yield benefit for each kg of mineral N applied) was greater in O4 compared with O2 for all crops.

1. Introduction

The market for organic food is expanding globally with an estimated growth rate of 10% in 2013 in the most advanced markets (Willer and Lernoud, 2015). The motivations among consumers that drive this growth are diverse, including health, ethical and environmental aspects (Thøgersen, 2011). Sweden, Denmark and Switzerland stand out in Europe with high market shares (above 6%) of organic food (Willer and Lernoud, 2015); however, other European countries also see growing market shares, although at the European scale organic food only constitute about 1% of total sales. This growing market for organic food requires expansion of the organic production, which already exceeds 10% in several European countries such as Sweden and Switzerland. Denmark is intensively cultivated with a large share of livestock production system (Dalgaard et al., 2014); here the share of agricultural land in organic farming was 8.1% in 2016, mostly based on dairy farming systems.

The organic farmed area in Denmark is anticipated to increase due to increased market demands for organic products (Dalgaard et al., 2011), which will require that most of the expansion of organic farming is within arable farming and monogastric livestock to fill the growing market in these areas. There is at the same time a need to strengthen the integrity and environmental sustainability of such organic production systems, since these aspects may influence the consumer preferences for

* Corresponding author.
E-mail address: jeo@agro.au.dk (J.E. Olesen).

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organic food in the long term. Organic farming practices do not always show lower environmental impacts than conventional practices, in particularly when expressed per unit product (Tuomisto et al., 2012). In addition, arable organic farming systems in Denmark are currently dependent on import of manure from conventional livestock production systems with an allowed import of conventional manure corresponding to 70 kg total-N ha^{-1}. There is an ambition to phase out this manure import, which will necessitate improved biological nitrogen (N) fixation (BNF) in the cropping system and improved on-farm recycling of nutrients as well as recycling of urban waste materials (Knudsen et al., 2014; Pugesgaard et al., 2014).

The expanding market for organic products enhances the competition also in the production sector, which calls for enhanced productivity in organic crop production. Such an increase in productivity will also contribute to reducing the environmental and climate footprints of the organic produce (Tuomisto et al., 2012; McGee, 2015). This means agricultural management should seek to reduce the yield gap between organic and conventional production systems, which will necessitate use of different measures to ensure crop nutrient supply and provide crop protection against weeds, pests and diseases other than those offered in conventional production (van Ittersum et al., 2013). Crop yields have been found on average to be 34% lower in organic than in comparable conventional systems (Seufert et al., 2012). However, this yield gap varies considerably depending on local conditions and the design and management of the organic systems, and nutrient inputs from external sources are often essential to maintain yields (Connor, 2013).

Building and managing soil fertility is an important component of organic farming systems, and organic farming systems are often considered to enhance soil organic matter content (Mäder et al., 2002; Gattinger et al., 2012). This soil fertility plays an important role in sustaining crop nutrient supply, in particular with N, which is the main limiting macronutrient in organic production (Badgley et al., 2007). The main source of soil fertility is the use of leguminous plants, retention of crop residues and application of animal manures and compost, all of which links to the composition of the crop rotation.

Crop rotation is the central tool that integrates the maintenance and development of soil fertility with different aspects of crop and livestock production in organic farming systems. Nutrient supply to crops depends on the use of legumes to add N to the system and limited inputs of supplementary nutrients, added in acceptable forms (Watson et al., 2002). The main elements of crop rotations that can contribute to enhancing crop nutrient supply is the enhancement of BNF through use of legume-based pastures for grazing, harvesting or mulching in green manures or the use of legume-based catch crops (Doltra and Olesen, 2013). In addition, the proper sequencing of fertility building versus fertility exploiting crops and the use of manures to match the needs of crops is essential for fertility management (Olesen et al., 2007). Crop rotations that include grass-clover as a whole year green manure for enhanced BNF may supply N through a pre-crop effect (Olesen et al., 2009) or by providing biomass that may be anaerobically digested to provide an organic fertilizer to target N demanding crops (Brozyna et al., 2013). Nevertheless, inclusion of whole year green manure crop occupy space at the expense of cash crops that reduces the total yield of the rotation (Olesen et al., 2002).

Crop protection problems also constitute major constraints to yields in organic farming system. These problems vary greatly among different crop types, in particular for diseases and pests that are mostly crop specific. Crop rotation measures may alleviate such problems by preventing the buildup of pest and disease pressures or enhance population of beneficial organisms (Eyre et al., 2009). The control of annual and perennial weeds in organic farming depend on the design of the crop rotations for suppressing weed propagation and the specific use of mechanical control measures (Rasmussen et al., 2006; Melander et al., 2012).

In this study, we used results from the first 12 years of a long-term field experiment conducted at three sites in Denmark to investigate the effects of different fertility building measures on the yield of different crops in organic systems with and without grass-clover as green manure (Olesen et al., 2000). The objective of the long-term experiment was to explore the possibilities for both short-term and long-term increases in organic cereal production through manipulation of crop rotation design on different soil types. The experiment included three rotation cycles at three sites varying in soil and climatic conditions. Organic farming yields are typically lower than conventional, but this varies greatly with cropping system design and manure input as well as local site conditions (Seufert et al., 2012). The objective of this study was improve understanding of this variation, and to explore which measures contribute most to reducing the yield gap between organic and conventional systems in North European climates. Further we wanted to explore whether the productivity of organic cropping systems change over time after conversion from conventional to organic practices. Since the management of the rotations varied over time, we primarily evaluated changes over time in terms of differences between different systems.

2. Materials and methods

2.1. Experimental sites

A long-term experiment was carried out in Denmark during 1997–2008 to compare different arable cropping systems in organic and conventional farming with crop rotations presented in Table 1. Three locations representing different soil and climatic conditions were included; Jyndevad situated in Southern Jutland on coarse sand (Orthic Haplohumod) contains 4.5% clay, 2.0% organic matter and pH 6.0 in the topsoil (0–25 cm); Foulum located in Central Jutland on loamy sand (Typic Hapludult) contains 8.8% clay, 3.8% organic matter and pH 6.5; Flakkebjerg located in Western Zealand on sandy loam (Typic Agrudalf) with 15.5% clay, 1.7% organic matter and pH 7.4. The topsoil exchangeable potassium content at onset of the experiment was 49, 131 and 98 mg K kg^{-1} dry soil for Jyndevad, Foulum and Flakkebjerg, respectively, and the Olsen-P contents were 52, 54 and 30 mg P kg^{-1}, respectively. A detailed description of the site and soil conditions is provided by Djurhuus and Olesen (2000) and Olesen et al. (2000).

Average annual temperature and rainfall were 7.9 °C and 964 mm, 7.3 °C and 704 mm, and 7.8 °C and 626 mm at Jyndevad, Foulum and Flakkebjerg, respectively, during the period 1961–1990 (Olesen et al., 2000). Table 2 shows the climatic conditions during the growing season (April to July) over the experimental period 1997–2008. There has been a gradual increase in mean temperature over the period, but no marked changes in precipitation. On annual basis, the mean temperature during 1997–2008 was about 1.1 °C above the 1961–1990 normal period.

2.2. Experimental design

The crop rotation experiment was originally designed only for organic farming treatments using a randomized factorial design with two replicates (Olesen et al., 2000). The experimental factors during the first two cycles (1997–2004) of the experiment were 1) proportion of grass-clover (as a green manure) or grain legumes in the crop rotation, 2) with (+CC) and without (−CC) catch crop, and 3) with (+M) and without (−M) animal manure. The experiment used 4-year crop rotations with all crops in the rotations being represented every year. This resulted in a total of 64 plots at each site (2 rotations × 2 catch crop treatments × 2 manure treatments × 4 crops × 2 replicates). Each replicate block was divided into two sub-blocks, and the three-way interactions between treatments were confounded with the sub-blocks. The plot sizes were 378, 216 and 169 m^2 at Jyndevad, Foulum and Flakkebjerg, respectively.

In the 3rd cycle from 2005 the −CC/−M combination was excluded from the organic cropping systems, and these plots were converted to conventional systems (C4). The rotation used in C4 was